

FREQUENCY DEPENDENT DAMPER

Field of the Invention

The present invention relates generally to dampers or shock absorbers adapted
5 for use in a suspension system such as the suspension system used for automotive
vehicles. More particularly, the present invention relates to a shock absorber which
utilizes a gas rather than hydraulic fluid as the damping medium.

Background of the Invention

10 Shock absorbers are used in conjunction with automotive suspension systems
to absorb unwanted vibrations which occur during driving. To absorb these unwanted
vibrations, shock absorbers are generally connected between the sprung portion (body)
and the unsprung portion (suspension) of the automobile. A piston is located within a
pressure tube of the shock absorber and the pressure tube is normally attached to the
15 unsprung portion of the vehicle. The piston is normally attached to the sprung portion
of the vehicle through a piston rod which extends through the pressure tube. The piston
divides the pressure tube into an upper working chamber and a lower working chamber
both of which are typically filled with a hydraulic liquid. Because the piston is able,
through valving, to limit the flow of the hydraulic fluid between the upper and lower
20 working chambers when the shock absorber is compressed or extended, the shock
absorber is able to produce a damping force which counteracts the vibration which
would otherwise be transmitted from the unsprung portion of the vehicle to the sprung
portion of the vehicle. In a dual tube shock absorber, a fluid reservoir or reserve
chamber is defined between the lower working chamber and the reserve chamber to
25 also produce a damping force which counteracts the vibrations which would otherwise

be transmitted from the unsprung portion of the vehicle to the sprung portion of the vehicle.

Shock absorbers filled with hydraulic liquid have met with continuous success throughout the automotive industry. While meeting with success in the automotive industry, hydraulic liquid filled shock absorbers are not without their problems. One problem with these prior art shock absorbers is that they are not sensitive to the frequency of the vibrations. Complex systems have been developed to modify these liquid filled shock absorbers to provide a shock absorber that is relatively soft for high frequency vibrations while being relatively stiff for low frequency vibrations. Other problems associated with the prior art hydraulic liquid filled shock absorbers include the variability in their damping forces due to temperature changes of the hydraulic liquid. As the temperature of the hydraulic liquid changes, the viscosity of the liquid also changes which significantly affects the damping force characteristics of the liquid. In addition, any aeration of the hydraulic liquid during operation of the shock absorber adversely affects the operation of the damper due to the introduction of a compressible gas into a non-compressible liquid. Finally, the hydraulic liquid adds to the weight of the shock absorber as well as presenting environmental concerns regarding the use and disposal of a hydraulic liquid.

The continued development of shock absorbers has been directed towards shock absorbers which do not use a hydraulic liquid for their damping medium. The replacement of the hydraulic liquid medium with an environmentally friendly gas medium provides the opportunity to overcome some of the problems associated with the hydraulic fluid damping medium shock absorbers.

Summary of the Invention

The present invention provides the art with a shock absorber that utilizes a gas, preferably air, as the damping medium. The use of the gas as the damping medium produces a frequency dependent damper or shock absorber which is significantly less sensitive to temperature when compared to hydraulic liquid dampers, is not adversely affected by aeration over time, is lower in weight and, especially when the gas is air, it is environmentally friendly due to the elimination of the hydraulic oil.

Other advantages and objects of the present invention will become apparent to those skilled in the art from the subsequent detailed description, appended claims and drawings.

Brief Description of the Drawings

In the drawings which illustrate the best mode presently contemplated for carrying out the present invention:

Figure 1 is an illustration of an automobile incorporating the unique gas filled frequency dependent damper in accordance with the present invention;

Figure 2 is a side view, partially in cross-section, of the unique gas filled frequency damper in accordance with the present invention;

Figure 3 is an enlarged cross-sectional view of the valving system incorporated into the piston assembly of the frequency dependent damper shown in Figure 2;

Figure 4 is an enlarged cross-sectional view of the rod guide assembly of the frequency dependent damper shown in Figure 2;

Figure 5 is an enlarged cross-sectional view of a piston assembly in accordance with another embodiment of the present invention;

Figure 6 is a side view, partially in cross-section, of a unique gas filled frequency dependent damper in accordance with another embodiment of the present invention; and

Figure 7 is a side view, partially in cross-section, of a unique gas filled frequency dependent damper in conjunction with an air spring in accordance with another embodiment of the present invention.

Detailed Description of the Preferred Embodiment

Referring now to the drawings in which like reference numerals designate like or corresponding parts throughout the several views, there is shown in Figure 1 a vehicle incorporating a suspension system having the frequency dependent dampers in accordance with the present invention and which is designated generally by the reference numeral 10. Vehicle 10 includes a rear suspension system 12, a front suspension system 14 and a body 16. Rear suspension system 12 includes a pair of independent suspensions adapted to operatively support a pair of rear wheels 18. Each rear independent suspension is attached to body 16 by means of a shock absorber 20 and a helical coil spring 22. Similarly, front suspension system 14 includes a pair of independent suspensions adapted to operatively support a pair of front wheels 24. Each independent front suspension is attached to body 16 by means of a shock absorber 26 and a helical coil spring 28. Rear shock absorbers 20 and front shock absorbers 26 serve to dampen the relative movement of the unsprung portion (i.e., front and rear suspension systems 12 and 14, respectively) of vehicle 10 with respect to the sprung portion (i.e., body 16) of vehicle 10. While vehicle 10 has been depicted as a passenger vehicle having independent front and rear suspensions, shock absorbers 20 and 26 may be incorporated into other types of vehicles having other types of suspensions and springs or into other types of applications, including, but not limited to, vehicles incorporating air springs, leaf springs, non-independent front and/or non-independent rear suspension systems. One of the unique features of the present invention is that if it is combined with an air spring, the air spring and the shock absorber can communicate with each other or the air spring and the shock absorber can be

separate units. Further, the term "shock absorber" as used herein is meant to refer to dampers in general and thus will include MacPherson struts, spring seat units, as well as other shock absorber designs known in the art.

Referring now to Figure 2, front shock absorber 26 is shown in greater detail.

5 While Figure 2 shows only shock absorber 26, it is to be understood that rear shock absorber 20 is or can be designed as a frequency dependent damper in accordance with the present invention. Rear shock absorber 20 would only differ from front shock absorber 26 in the way it is adapted to be connected to the sprung and unsprung portions of vehicle 10 and in the dimensions of the various components. Shock
10 absorber 26 comprises a pressure tube 30, a piston assembly 32, a piston rod 34 and a rod guide assembly 36.

Pressure tube 30 defines a working chamber 42. Working chamber 42 is filled with a gas, preferably air, at a specified pressure to act as the damping medium. Piston
15 assembly 32 is slidably disposed within working chamber 42 and divides working chamber 42 into an upper working chamber 44 and a lower working chamber 46. A seal assembly 48 is disposed between piston assembly 32 and pressure tube 30 to permit sliding movement of piston assembly 32 with respect to pressure tube 30 without generating undue frictional forces as well as sealing upper working chamber 44 from lower working chamber 46. Piston rod 34 is attached to piston assembly 32 and
20 extends through upper working chamber 44 and through rod guide assembly 36 which closes the upper end of pressure tube 30. The end of piston rod 34 opposite to piston assembly 32 is adapted to be secured to the sprung portion of vehicle 10. The end of pressure tube 30 opposite to rod guide assembly 36 is closed by an end cap 50 and end cap 50 is adapted to be connected to the unsprung portion of vehicle 10. While piston
25 rod 34 is shown adapted for being connected to the sprung portion of vehicle 10 and end cap 50 is adapted for being connected to the sprung portion of vehicle 10, due to the use of a gas as the pressure medium, it is within the scope of the present invention

to have piston rod 34 adapted to attach to the unsprung portion of vehicle 10 and end cap 50 adapted to attach to the sprung portion of vehicle 10 if desired.

Referring now to Figures 2 and 3, piston assembly 32 comprises a piston body 52, a compression valve assembly 54 and a rebound or extension valve assembly 56.

5 Piston rod 34 defines a reduced diameter section 58 onto which compression valve assembly 54, piston body 52 and rebound valve assembly 56 are located. A nut 60 secures piston assembly 32 onto section 58 of piston rod 34 with compression valve assembly 54 abutting a shoulder 62 located on piston rod 34, piston body 52 abutting compression valve assembly 54, rebound valve assembly 56 abutting piston body 52

10 and nut 60 abutting rebound valve assembly 56 and threadingly engaging piston rod 34 to retain piston assembly 32 on piston rod 34.

Seal assembly 48 comprises a pair of annular seals located between piston body 52 and pressure tube 30. Seal assembly 48 is held in position by a plurality of grooves 64 formed in piston body 52. Seal assembly 48 permits sliding movement of piston

15 body 52 with respect to pressure tube 30 without generating unique frictional forces as well as providing a seal between upper working chamber 44 and lower working chamber 46. This dual roll played by seal assembly 48 is extremely important for pneumatic shock absorber 26 due to the high pressures generated in working chambers 44 and 46 and the continued need for limiting the sliding forces generated between piston

20 assembly 32 and pressure tube 30.

Piston body 52 defines a plurality of compression passages 70 and a plurality of extension passages 72. During a compression movement of shock absorber 26, gas flows between lower working chamber 46 and upper working chamber 44 through passages 70 as described below. During an extension movement of shock absorber

25 26, gas flows between upper working chamber 44 and lower working chamber 46 through passages 72 as described below.

Compression valve assembly 54 comprises a stop 74, a pair of annular seals 76 and a valve plate 78. Valve plate 78 is normally positioned against annular seals 76 to normally close the plurality of compression passages 70. During a compression stroke of shock absorber 26, the gas in lower working chamber 46 is compressed including the gas located within the plurality of compression passages 70. The compressed gas located within compression passages 70 exerts a force on valve plate 78 which will remain seated closing passages 70 until the force created by the gas pressure exceeds the bending stiffness of valve plate 78. When the load produced by the gas pressure exceeds the bending stiffness of valve plate 78, valve plate 78 will deflect away from seals 76 to allow gas flow from lower working chamber 46 to upper working chamber 44 through passages 70.

Extension valve assembly 56 comprises a valve stop 84, a pair of annular seals 86 and a valve plate 88. Valve plate 88 is normally positioned against seals 86 to normally close the plurality of extension passages 72. During an extension stroke of shock absorber 26, the gas in upper working chamber 44 is compressed including the gas located within the plurality of extension passages 72. The compressed gas located within extension passages 72 exerts a force on valve plate 88 which will remain seated closing passages 72 until the force created by the gas pressure exceeds the bending stiffness of valve plate 88. When the load produced by the gas pressure exceeds the bending stiffness of valve plate 88, valve plate 88 will deflect away from seals 86 to allow gas flow from upper working chamber 44 to lower working chamber 46 through passages 72.

Referring now to Figures 2 and 4, rod guide assembly 36 provides both a sealing function for shock absorber 26 as well as a lubricating function. Rod guide assembly 36 comprises a main housing 90, an upper seal assembly 92, a lower seal assembly 94, a retainer 96 and a wiper seal 98. Main housing 90 is fit within pressure tube 30 with a pair of seals 100 sealing the interface between housing 90 and pressure tube 30.

Retainer 96 secures main housing 90 within pressure tube 30. Wiper seal 98 is located between housing 90 and retainer 96 and acts to wipe foreign material off of piston rod 34 during the stroking of shock absorber 26. Housing 90 defines an external cavity 102 located between the pair of seals 100. External cavity 102 can be filled with oil to aid in the sealing between housing 90 and pressure tube 30. Housing 90 defines an internal cavity 104 within which upper seal assembly 92 and lower seal assembly 94 are located.

Upper seal assembly 92 comprises a dynamic seal 112 located between housing 90 and piston rod 34, a static seal 114 located between dynamic seal 112 and housing 90 and a retainer 116 attached to housing 90 to retain upper seal assembly 92 within cavity 104.

Lower seal assembly 94 is similar to upper seal assembly 92 and it comprises a dynamic seal 122, a static seal 124, a seal housing 126, a first retainer 128, and a second retainer 130. Dynamic seal 122 is located between seal housing 126 and piston rod 34. Static seal 124 is located between dynamic seal 122 and housing 126. First retainer 128 is attached to housing 90 to position lower seal assembly 94 within cavity 104. Second retainer 130 is attached to housing 90 to retain lower seal assembly within cavity 104.

Housing 90, upper seal assembly 92 and lower seal assembly 94 cooperate to form a chamber 140 within cavity 104 which is filled with lubricating oil to seal and lubricate the movement of piston rod 34 through rod guide assembly 36. A pair of seals 142 located between housing 90, housing 126 and first retainer 128 isolates chamber 140 from upper working chamber 44. During assembly of shock absorber 26, chamber 140 is filled with a specified amount of lubricant. Upper seal assembly 92 isolates chamber 140 from the outside environment and lower seal assembly 92 isolates chamber 140 from upper working chamber 44. Thus, the lubricant within chamber 140

of shock absorber 26 seals working chamber 42 to allow it to maintain its original gas charge while simultaneously providing lubrication for the movement of piston rod 34.

A valve body 150 is secured to pressure tube 30 such that axial motion with respect to pressure tube 30 is prohibited. Valve body 150 defines a gas chamber 152
5 located below valve body 150 and below lower working chamber 46. A tunable restriction 154 extends through valve body 150 to provide communication between lower working chamber 46 and gas chamber 152.

Gas filled shock absorber 26 described above provides a frequency dependent damper which can be tuned to specific performance requirements for specific
10 applications. During compression and extension movements of a prior art liquid filled shock absorber, the liquid moves from either the lower working chamber to the upper working chamber or from the upper working chamber to the lower working chamber. This provides frequency versus dissipation response curves which continue to rise at an ever increasing rate as the frequency of the damped vibration increases leading to
15 an exponential shaped curve at higher frequencies. The present invention provides the suspension system designer the opportunity to flatten the shape of this curve.

The flattening out of this curve is due to the compressibility of a gas versus the non-compressibility of a liquid. During low speed or low frequency movements of shock absorber 26, minimal compression of the gas occurs and movement of piston assembly
20 32 easily transfers gas between working chambers 44 and 46 of pressure tube 30. As the frequency of the movement increases, compression of the gas will also increase, changing the dissipation as the compressed gas begins to work like a gas spring. The specific point at which the gas shock curve bends away from the liquid shock curve can be tuned by selecting different sizes for passages 70 and 72 and different stiffnesses
25 for valve plates 78 and 88. In addition to changing the shape of the frequency versus dissipation response curves, the height of the curve can also be tuned by changing the

initial gas pressure within working chamber 42 as well as changing the axial position of valve body 150.

The dual points of tunability for shock absorber 26 allows for tuning shock absorber 26 to both the lower car body natural frequencies (1-5 Hz) as well as the higher wheel hop natural frequencies (10-20 Hz) to optimize performance of shock absorber 26 at both of these frequencies. The prior art liquid shock absorbers could be tuned to one specific frequency but the remaining frequency responses were a result of the shape of the curve which could not be altered.

Referring now to Figure 5, a piston assembly 32' is illustrated. Piston assembly 32' is designed to be a direct replacement for piston assembly 32. Piston assembly 32' comprises a piston body 52' and a tunable restriction 70'. Tunable restriction 70' replaces passages 70 and 72 of piston assembly 32 and provides communication between upper working chamber 44 and lower working chamber 46. The damping characteristics for a shock absorber 26 which incorporates piston assembly 32' is controlled by the size of tunable restriction 70'. The function, operation and advantages listed above for shock absorber 26 utilizing piston assembly 32 are the same for shock absorber 26 when piston assembly 32' replaces piston assembly 32.

Referring now to Figure 6, a shock absorber 226 in accordance with another embodiment of the present invention is illustrated. Shock absorber 226 comprises pressure tube 30, piston assembly 32, piston rod 34, a rod guide assembly 236 and a chamber tube 238.

One of the problems associated with shock absorber 26 shown in Figure 2 is the addition of gas chamber 152 increases the overall length of shock absorber 26 without increasing the available stroke for shock absorber 26. Shock absorber 226 addresses this issue by having chamber tube 238 define a gas chamber 350 which is concentric with working chamber 42 defined by pressure tube 30. In order to accommodate chamber tube 238, rod guide assembly 236 replaces rod guide assembly 36. Rod guide

assembly 236 is the same as rod guide assembly 36 except that retainer 96 has been replaced with retainer 296. Retainer 296 is the same as retainer 96 except for having a flanged section 298 which extends radially outward to mate with chamber tube 238 to seal gas chamber 350. In addition, end cap 50 of shock absorber 26 has been replaced with end cap 250. End cap 250 is the same as end cap 50 except that end cap 250 extends radially outward to mate with chamber tube 238 to seal gas chamber 350. The function, operation and advantages for shock absorber 226 are the same as those listed above for shock absorber 26.

Referring now to Figure 7, a shock absorber 426 in accordance with another embodiment of the present invention is illustrated. Shock absorber 426 comprises pressure tube 30, piston assembly 32, piston rod 34 and a rod guide assembly 436.

When vehicle 10 includes an air spring assembly 422 in place of coil springs 22 and/or coil springs 28, the volume of the compressed gas can be utilized as a gas chamber 550 in place of chamber 150 or 350 for shock absorber 426.

Air spring assembly 422 comprises a flexible bladder 424 which is secured to shock absorber 426 using a retainer 428 and which is secured to an upper mount assembly 430 by a retainer 432. Bladder 424 defines chamber 550 which contains pressurized gas for supporting body 16 of vehicle 10. In order to utilize chamber 550 for the tuning of shock absorber 426, a tunable restriction 554 needs to be provided through rod guide assembly 436 to allow gas communication between upper working chamber 44 and chamber 550. While not specifically illustrated, rather than provide tunable restriction 554 through rod guide assembly 436, lower working chamber 46 can communicate with chamber 550 through either an exteriorly located or an interiorly located tunable restriction if desired. Rod guide assembly 436 is the same as rod guide assembly 36 with the exception of incorporation tunable restriction 554. The function, operation and advantages of shock absorber 426 are the same as those detailed above for shock absorber 26.

While the above detailed description describes the preferred embodiment of the present invention, it should be understood that the present invention is susceptible to modification, variation and alteration without deviating from the scope and fair meaning of the subjoined claims.

11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100
101
102
103
104
105
106
107
108
109
110
111
112
113
114
115
116
117
118
119
120
121
122
123
124
125
126
127
128
129
130
131
132
133
134
135
136
137
138
139
140
141
142
143
144
145
146
147
148
149
150
151
152
153
154
155
156
157
158
159
160
161
162
163
164
165
166
167
168
169
170
171
172
173
174
175
176
177
178
179
180
181
182
183
184
185
186
187
188
189
190
191
192
193
194
195
196
197
198
199
200
201
202
203
204
205
206
207
208
209
210
211
212
213
214
215
216
217
218
219
220
221
222
223
224
225
226
227
228
229
230
231
232
233
234
235
236
237
238
239
240
241
242
243
244
245
246
247
248
249
250
251
252
253
254
255
256
257
258
259
260
261
262
263
264
265
266
267
268
269
270
271
272
273
274
275
276
277
278
279
280
281
282
283
284
285
286
287
288
289
290
291
292
293
294
295
296
297
298
299
300
301
302
303
304
305
306
307
308
309
310
311
312
313
314
315
316
317
318
319
320
321
322
323
324
325
326
327
328
329
330
331
332
333
334
335
336
337
338
339
340
341
342
343
344
345
346
347
348
349
350
351
352
353
354
355
356
357
358
359
360
361
362
363
364
365
366
367
368
369
370
371
372
373
374
375
376
377
378
379
380
381
382
383
384
385
386
387
388
389
390
391
392
393
394
395
396
397
398
399
400
401
402
403
404
405
406
407
408
409
410
411
412
413
414
415
416
417
418
419
420
421
422
423
424
425
426
427
428
429
430
431
432
433
434
435
436
437
438
439
440
441
442
443
444
445
446
447
448
449
450
451
452
453
454
455
456
457
458
459
460
461
462
463
464
465
466
467
468
469
470
471
472
473
474
475
476
477
478
479
480
481
482
483
484
485
486
487
488
489
490
491
492
493
494
495
496
497
498
499
500
501
502
503
504
505
506
507
508
509
510
511
512
513
514
515
516
517
518
519
520
521
522
523
524
525
526
527
528
529
530
531
532
533
534
535
536
537
538
539
540
541
542
543
544
545
546
547
548
549
550
551
552
553
554
555
556
557
558
559
560
561
562
563
564
565
566
567
568
569
570
571
572
573
574
575
576
577
578
579
580
581
582
583
584
585
586
587
588
589
590
591
592
593
594
595
596
597
598
599
600
601
602
603
604
605
606
607
608
609
610
611
612
613
614
615
616
617
618
619
620
621
622
623
624
625
626
627
628
629
630
631
632
633
634
635
636
637
638
639
640
641
642
643
644
645
646
647
648
649
650
651
652
653
654
655
656
657
658
659
660
661
662
663
664
665
666
667
668
669
670
671
672
673
674
675
676
677
678
679
680
681
682
683
684
685
686
687
688
689
690
691
692
693
694
695
696
697
698
699
700
701
702
703
704
705
706
707
708
709
710
711
712
713
714
715
716
717
718
719
720
721
722
723
724
725
726
727
728
729
730
731
732
733
734
735
736
737
738
739
740
741
742
743
744
745
746
747
748
749
750
751
752
753
754
755
756
757
758
759
760
761
762
763
764
765
766
767
768
769
770
771
772
773
774
775
776
777
778
779
780
781
782
783
784
785
786
787
788
789
790
791
792
793
794
795
796
797
798
799
800
801
802
803
804
805
806
807
808
809
810
811
812
813
814
815
816
817
818
819
820
821
822
823
824
825
826
827
828
829
830
831
832
833
834
835
836
837
838
839
840
841
842
843
844
845
846
847
848
849
850
851
852
853
854
855
856
857
858
859
860
861
862
863
864
865
866
867
868
869
870
871
872
873
874
875
876
877
878
879
880
881
882
883
884
885
886
887
888
889
890
891
892
893
894
895
896
897
898
899
900
901
902
903
904
905
906
907
908
909
910
911
912
913
914
915
916
917
918
919
920
921
922
923
924
925
926
927
928
929
930
931
932
933
934
935
936
937
938
939
940
941
942
943
944
945
946
947
948
949
950
951
952
953
954
955
956
957
958
959
960
961
962
963
964
965
966
967
968
969
970
971
972
973
974
975
976
977
978
979
980
981
982
983
984
985
986
987
988
989
990
991
992
993
994
995
996
997
998
999
1000